SEDIMENT BUDGET: MISSISSIPPI SOUND BARRIER ISLANDS*

MARK R. BYRNES[1], JULIE D. ROSATI[2], SARAH F. GRIFFEE[1]

1. *Applied Coastal Research and Engineering, Inc., 766 Falmouth Road, Suite A-1, Mashpee, MA 02649. mbyrnes@appliedcoastal.com, sgriffee@appliedcoastal.com.*
2. *U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, 109 St. Joseph Street, Mobile, AL, USA. Julie.D.Rosati@usace.army.mil.*

Abstract: Historical shoreline and bathymetric survey data were compiled for the barrier islands and passes fronting Mississippi Sound to develop a regional sediment budget spanning a 90-year period. Net littoral sand transport along the islands and passes is primarily unidirectional (east-to-west). Beach erosion along the east side of each island and sand spit deposition to the west result in an average sand flux of about 430,000 cy/yr throughout the barrier island system. Dog Keys Pass, located updrift of East Ship Island, is the only inlet that is a net sediment sink. It also is the widest pass in the system and has two active channels and ebb shoals. As such, a deficit of sand exists along East Ship Island. Littoral sand transport decreases rapidly on West Ship Island, where exchange of sand between islands terminates because of wave sheltering from shoals and islands of the old St. Bernard delta complex, Louisiana.

Introduction

Five barrier islands create the offshore boundary for Mississippi Sound, including four permanent passes between the islands (Petit Bois Pass, Horn Island Pass, Dog Keys Pass, and Ship Island Pass). From east to west, the barrier islands are Dauphin, Petit Bois, Horn, Ship (East and West), and Cat. These islands are approximately 8 to 14 miles offshore and separate Mississippi Sound from the Gulf of Mexico (Figure 1). Tidal passes promote exchange of sediment and water between marine waters of the Gulf of Mexico and brackish waters of Mississippi Sound and interrupt the net flow of littoral sand to the west from Dauphin Island. Petit Bois Pass is about 5 miles wide, with a poorly developed channel and system of shoals separating Dauphin and Petit Bois Islands. Horn Island Pass is approximately 3.5 miles wide and is occupied by the Pascagoula Ship Channel with a regularly maintained channel depth and width. Dog Keys and Little Dog Keys Passes separate Horn and East Ship Islands as two entrance channels with well-developed ebb shoals (about 6 miles between the islands). Ship Island Pass exists along the western end of Ship Island and encompasses the Gulfport Ship Channel. Water depths in passes are generally 15 feet or less, except in pass channels where maximum depths range from about 29 to 64 feet. The barrier islands provide the

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14. ABSTRACT

Historical shoreline and bathymetric survey data were compiled for the barrier islands and passes fronting Mississippi Sound to develop a regional sediment budget spanning a 90-year period. Net littoral sand transport along the islands and passes is primarily unidirectional (east-to-west). Beach erosion along the east side of each island and sand spit deposition to the west result in an average sand flux of about 430,000 cy/yr throughout the barrier island system. Dog Keys Pass, located updrift of East Ship Island, is the only inlet that is a net sediment sink. It also is the widest pass in the system and has two active channels and ebb shoals. As such, a deficit of sand exists along East Ship Island. Littoral sand transport decreases rapidly on West Ship Island, where exchange of sand between islands terminates because of wave sheltering from shoals and islands of the old St. Bernard delta complex, Louisiana.

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first line of defense for the mainland coast and Sound navigation channels, serving to decrease wave activity in their shadow (e.g., Stone and McBride 1998).

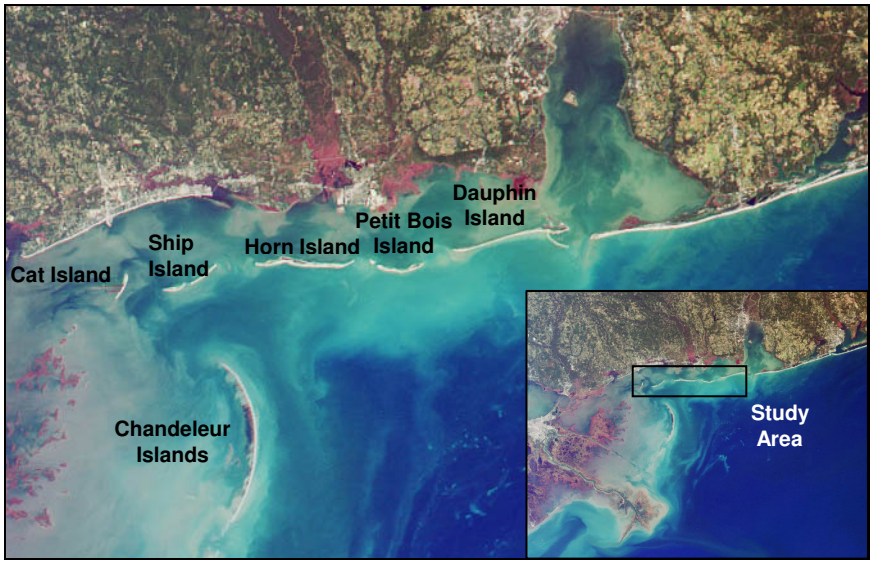

Fig. 1. Location diagram for the Mississippi Sound barrier island study area (10/15/2001 image).

A series of devastating hurricanes over the past 15 years has significantly reduced the width and elevation of barrier beaches, exposing mainland beaches, infrastructure, and navigation channels to increasing storm energy. The exchange of sediment between the barrier island littoral drift system, navigation channels, inlet shoals between the islands, and Mississippi Sound controls the littoral sand budget. Geomorphic changes caused primarily by storm processes document cause and effect relationships that are often difficult to capture with short-term, site specific process measurements. The primary purpose for analyzing historical shoreline and bathymetry data sets is to document the evolution of beach, nearshore, and channel environments most directly influenced by major storms for determining net sediment transport pathways, quantifying changes on a regional scale, and developing a long-term detailed sediment budget. This paper provides results of data compiled and analyzed for the Mississippi Sound barrier island coast to document historical sediment transport pathways and quantities controlling geomorphic change since the mid-1800s.

Physical Setting

According to Otvos and Carter (2008) and Otvos and Giardino (2004), the Mississippi Sound barrier islands formed during a deceleration in sea-level rise approximately 5,700 to 5,000 years ago. At that time, the core of Dauphin Island at

its eastern end was the only subaerial feature in the location of the modern barrier island system. Sand from east of Mobile Pass was transported west via Mobile Pass ebb-tidal shoals and eastern Dauphin Island, depositing as elongate sand spits and barrier islands fronting Mississippi Sound. Beginning approximately 3,500 years ago, the Mississippi River flowed east of New Orleans toward Mississippi Sound, creating the St. Bernard Delta (Otvos and Giardino 2004). Deltaic deposition extended over the western end of the Mississippi barrier island system, west of Cat Island. By about 2,400 years ago, fluvial sediment from the expanding St. Bernard Delta created shoals as far west as Ship Island (Otvos 1979), changing wave propagation patterns and diminishing west-directed sand supply to Cat Island. With changing wave patterns and reduced sand supply from the east, the eastern end of Cat Island began to erode, resulting in beach sand transport perpendicular to original island orientation (Rucker and Snowden 1989; Otvos and Giardino 2004).

Along the Mississippi Sound barrier island chain, persistent sand transport from the east has been successful at maintaining island configuration relative to rising sea level; however, reduced sand transport toward Ship Island has resulted in increased island erosion and segmentation from tropical storms (Rucker and Snowden 1989). Waller and Malbrough (1976), Byrnes et al. (1991), and Morton (2008) documented changes in island configuration since the mid-1800s, illustrating westward migrating islands and inlets, with greatest island changes along Ship Island where sand supply is limited at the end of the littoral transport system.

Channel Dredging and Placement History

The study area is traversed by many navigation channels: two channels that extend through Horn Island Pass (Pascagoula Ship Channel) and Ship Island Pass (Gulfport Ship Channel); the Gulf Intracoastal Waterway (GIWW) that runs east-west through Mississippi Sound; and five Sound navigation channels that include Gulfport, Biloxi, Pascagoula, Bayou Casotte, and Bayou La Batre (Figure 2). Sediment dredged from the GIWW and other channels extending through Mississippi Sound (primarily silt and clay) has been side-cast or placed in designated disposal areas outside the littoral zone. As such, dredging and placement activities in the Sound do not influence the sand budget for the barrier islands. However, channel dredging and placement of beach sand adjacent to the barrier islands must be considered when quantifying the littoral sediment budget. Figures 3 and 4 illustrate cumulative maintenance dredging quantities since channel authorization at Horn Island Pass and Ship Island Pass. The timing for authorized channel dimension changes is shown on each diagram, and the rate at which sand has been extracted from the channel is documented for specific periods when dredging quantities are consistent.

The littoral sand budget is a balance between natural sand sources to the system, depositional zones or sinks within the system, natural sediment transport to

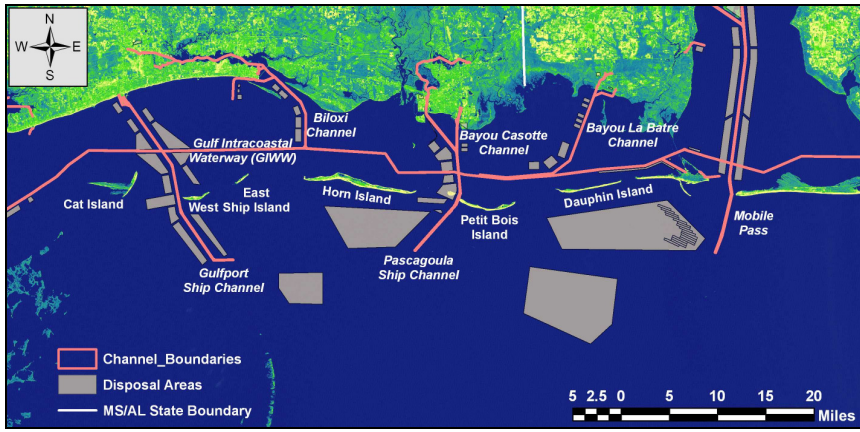

Fig. 2. Mississippi and Alabama coast west of Mobile Pass, illustrating navigation channels and dredged material disposal areas. Background image was acquired via Landsat on February 2, 2010.

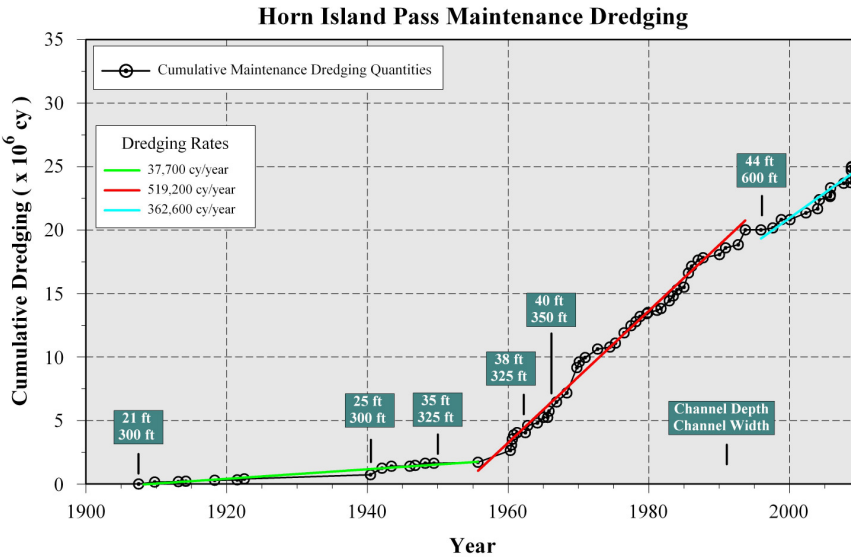

Fig. 3. Cumulative maintenance dredging volumes and sand dredging rates for Horn Island Pass.

locations outside the littoral zone, and placement of dredged material from the littoral zone seaward of the zone of active sand transport. When the quantity of channel maintenance dredging equals the quantity placed in the littoral zone, the sand budget is balanced. For Horn Island Pass, the difference between littoral zone placement and maintenance dredging is about -3.9 million cubic yards (cy; deficit to the littoral sand budget). For Ship Island Pass, the difference is about -5.3 million

cy; however, Ship Island Pass is the terminus to longshore transport within the barrier island system so this deficit has no direct impact on downdrift beaches.

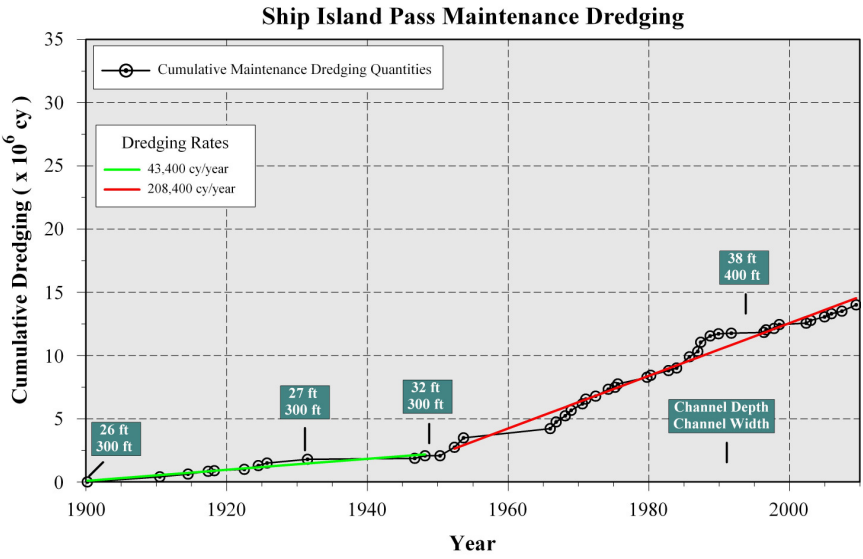

Fig. 4. Cumulative maintenance dredging volumes and sand dredging rates for Ship Island Pass (navigation channel was realigned west of its original location in the early 1990s).

Shoreline Dynamics

Eleven regional shoreline surveys were used to document historical changes between Dauphin Island, AL (east) and Cat Island, MS (west) for the period1847/49 to 2010. Shoreline and beach evolution for the barrier islands fronting Mississippi Sound are driven by longshore transport processes associated with storm and normal wave and current conditions (Waller and Malbrough 1976; Shabica et al. 1984; Byrnes et al. 1991; Morton 2008). Although beach erosion and washover deposition are processes that have influenced island changes, the dominant mechanism by which sand is redistributed along the barrier islands and in the passes is by longshore currents generated by wave approach from the southeast. Geomorphic changes along the islands illustrate the dominance of net sand transport from east to west.

Beach erosion along the Gulf shoreline of the low-lying sand spit of Dauphin Island, in addition to sand transport onto the beach from Pelican Island (subaerial sand deposit on the west lobe of the Mobile Pass ebb shoal), supplied sediment for rapid and continuous deposition at the western end of Dauphin Island between 1848 and

2010 (Byrnes et al. 2010). The island elongated about 5.4 miles west during this time at an average rate of about 150 ft/yr. Net westward movement forced Petit Bois Pass in the same direction, resulting in net erosion along the eastern end of Petit Bois Island and net widening of the pass. Most sediment eroded from eastern Petit Bois Island was deposited along a sand spit at the western end of the island and in the navigation channel at Horn Island Pass. Since 1957, the west end of Petit Bois Island has remained in its present location because it abuts the maintained navigation channel. Before this time, westward island migration forced Horn Island Pass and eastern Horn Island to the west at about 127 ft/yr. As a result, western Horn Island migrated to the west.

Sand transported west along Horn Island was deposited in a 2.9 mile-long, relatively wide sand spit that projected into Dog Keys Pass (Figure 5). Westward island growth produced a narrower inlet as the primary channel at Dog Keys Pass was forced westward toward Dog Island and East Ship Island. Little Dog Keys Pass (to the west of Dog Island) originated as a secondary channel at the entrance, but as Horn Island migrated westward historically, Dog Island eroded and dispersed into entrance shoals as hydraulics changed in the inlet. Presently, Little Dog Keys Pass is the deepest channel between Horn and East Ship Islands and it reduces sand bypassing to East Ship Island.

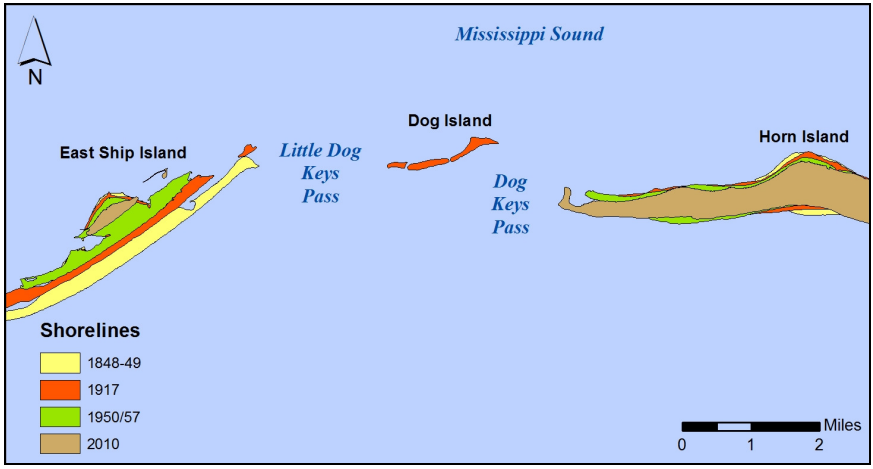

Fig. 5. Composite island changes for western Horn Island and East Ship Island, 1848 to 2010.

Ship Island is the downdrift terminus of the Mississippi Sound barrier islands and is the most vulnerable island in the barrier system due to its distance from the sand source. Historical data illustrate that the central portion of the island has been narrow and low, and highly susceptible to breaching during tropical cyclones. The east end of the island is strongly erosive, and sand transported from this area

deposits at the west end of the island, resulting in net westward migration by about 4,500 feet between 1848 and 2010. Sand transport from Dog Keys Pass has never been able to counteract beach erosion along the eastern end of Ship Island, so chronic erosion in this area is pervasive. Beach erosion and overtopping along East Ship Island has been so persistent since 1969 that the island is in danger of complete degradation within the next 10 to 20 years.

Seafloor Morphology and Change

Although shoreline change patterns (two dimensions) contain a record of the influence of coastal processes on beach response, regional assessment of inlet and nearshore morphology (three dimensions) better reveals dominant processes controlling the magnitude and direction of sediment transport throughout a coastal system. Mississippi Sound and nearshore were surveyed on four separate occasions between 1847/55 and 2005/10, providing ample data for documenting beach and inlet evolution, regional sediment transport pathways, net transport quantities, potential influence of engineering activities, and the exchange of sediment between ebb shoals and adjacent shorelines for determining regional sediment budgets. Because the sediment budget presented below encompasses the period 1917/20 to 2005/10, a description of seafloor morphology and change will focus on this period.

The most prominent seafloor features throughout the study area are channels and shoals associated with passes between the barrier islands. A series of inlet shoals and channels on the 1917/20 (Figure 6) seafloor reflect the redistribution and conveyance of littoral sand between barrier islands within a relatively narrow zone of sand transport bound by the 30- to 35-ft depth contours in the Gulf and the 10- to 15-ft contours in the Sound (all elevations relative to the North American Vertical Datum 1988 [NAVD]). This approximate 1 to 4 mile wide nearshore region (narrower for islands, wider for passes) encompasses the zone of littoral sand transport through which islands and inlets fronting Mississippi Sound have evolved

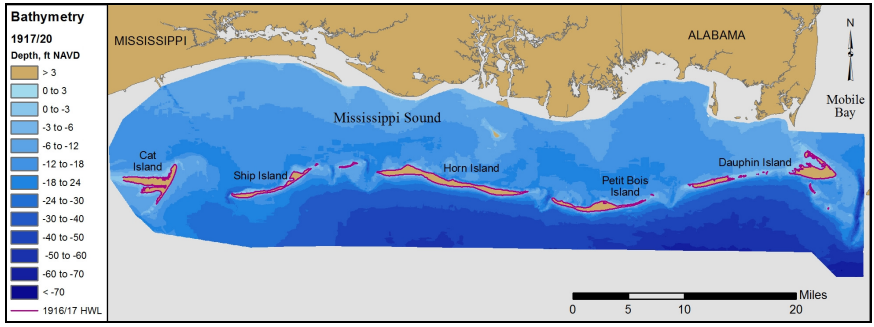

Fig. 6. Regional bathymetric surface for the study area, 1917/20.

in response to storm and normal coastal processes. The ebb shoal at Dog Keys Pass was the most extensive shoal system along the barrier island chain west of Mobile Pass, followed by shoals associated with Horn Island Pass. Although Ship Island Pass was the deepest natural inlet west of Mobile Pass, ebb shoal deposits were not well developed, perhaps reflecting a natural decrease in sand transport (and therefore, wave energy) toward the west end of Ship Island (terminal point in the longshore transport system). Inlet shoals and channels at all entrances were oriented to the west, consistent with the dominant direction of net sand transport resulting in westward lateral growth of the islands. Between the passes, offshore contours appeared relatively straight and parallel to shoreline orientation.

Most obvious changes on the 2005/10 seafloor are those associated with island breaching on Ship and Dauphin Islands (Figure 7). From east to west, westward island growth of Dauphin Island effectively closed the main channel at Petit Bois Pass. The entrance remained wide, but flow within the entrance must have diminished as the main channel became filled in response to dominant west-directed longshore sand transport. As the eastern end of Petit Bois Island eroded, sand spit growth on the western end of the island continued until it encountered the Pascagoula navigation channel at Horn Island Pass. Littoral sand transported to and dredged from the channel has been placed primarily in the littoral zone west of the channel. The small island west of the channel has been a primary dredged material disposal site for decades and slowly feeds sand west toward Horn Island.

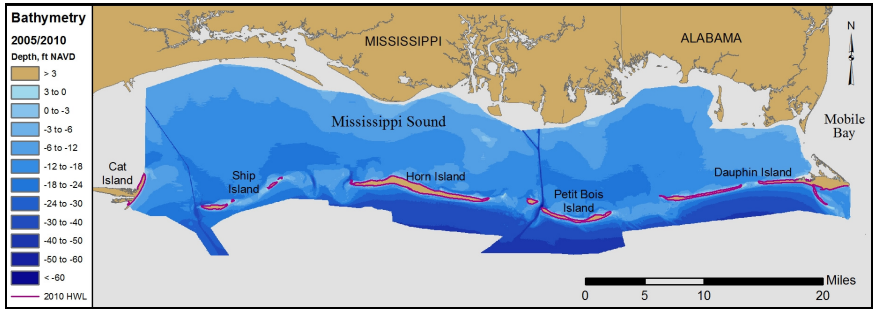

Fig. 7. Regional bathymetric surface for the study area, 2005/10.

Erosion along the eastern end of Horn Island exceeded subaerial deposition along the west end of the island since 1917/20. Westward growth of the island caused shoaling in Dog Keys Pass and pushed the channel west, invoking a switch in channel flow dominance at the entrance. The 2005/10 bathymetric surface illustrates that Little Dog Keys Pass is now deeper and more dominant than at any time in the historical record. The ebb shoal at Dog Keys Pass remains large, but the shoal at Little Dog Keys Pass has grown since 1917/20, implying that it has become a sink

to littoral sand transport from the east. Consequently, sand transport to East Ship Island has been reduced, resulting in a net deficit to the island.

As a result of inlet shoal and channel dynamics at Dog Keys Pass, Ship Island has experienced significant changes between 1917/20 and 2005/2010. The eastern half of the island is close to becoming a shoal as the island responds to a net deficit in sand from Dog Keys Pass and the brunt of a series of devastating tropical cyclones since 1969. Transport dynamics naturally are reduced toward Ship Island as the direction of open-Gulf wave energy becomes more restricted west of Horn Island in the shadow of the St. Bernard Delta (Otvos 1979; Rucker and Snowden 1989).

Quantifying change trends throughout the Mississippi Sound barrier island system was completed for the period 1917/20 to 2005/10 (Figure 8) to develop a long-term sediment budget. Erosion along the western half of Dauphin Island provided vast quantities of sand for westward island growth, washover deposition, and development of subaqueous shoals within Petit Bois Pass. Westward sediment transport along Petit Bois Island was supplied by beach erosion along the eastern end of the island and transport from Petit Bois Pass. Much of this sand was deposited in the navigation channel at Horn Island Pass (about 279,000 cy/yr), but substantial quantities also were deposited on the eastern lobe of the ebb shoal and at the western end of Petit Bois Island (Figure 8). Beach erosion along the eastern end of Horn Island supplied sand for spit growth at the western end of the island and shoal deposition at Dog Keys Pass. As the entrance channel and shoals were forced westward, the easternmost portion of the old ebb shoal eroded and supplied sand to new shoals west of its location. This trend continued along Ship Island where beach erosion along East Ship Island provided a source of sediment to West Ship Island and for storm washover deposits north of the island. Overall, sand erosion and deposition patterns within the Mississippi Sound barrier island system exhibited consistent trends throughout the period of record, even in the presence of channel dredging activities at Horn Island Pass (Pascagoula Bar Channel).

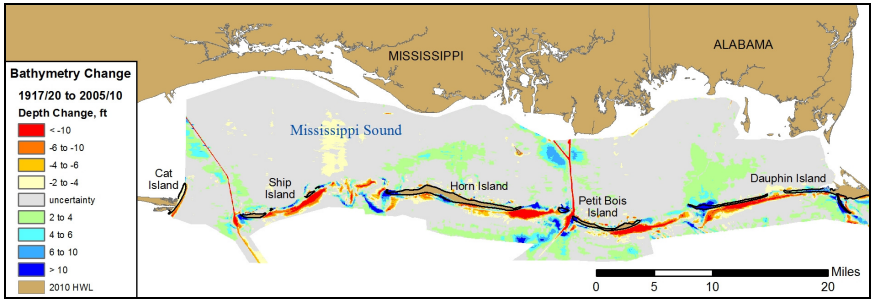

Fig. 8. Bathymetric change between 1917/20 and 2005/10 for the Mississippi Sound barrier islands. Hot colors represent erosion (yellow to red), and cool colors represent deposition (green to blue).

Regional Sediment Budget

Zones of erosion and accretion were identified throughout the sediment budget control area based on bathymetric change analysis (Figure 8). Overall, ebb shoals at all entrances were net depositional (sediment sinks). Beach and nearshore environments along the east ends of the islands were net erosional (sediment sources). The dominant direction of littoral transport is from east to west, and sand from beaches and nearshore areas along the western Florida and Alabama coast supplied material to downdrift barrier beaches fronting Mississippi Sound. Net west-directed transport deposited sand along the east side of the passes as elongated sand spits and shoals in the entrances. Much of the sand dredged from Horn Island Pass was placed on the west lobe of the ebb shoal, transferring littoral sand derived from beaches east of the navigation channel to the downdrift littoral zone. However, it was determined from dredging records that about 3.9 million cy of littoral sand (43,000 cy/yr) dredged from the channel between 1917/18 and 2009 may not have been returned to the littoral zone west of the channel, potentially creating a net long-term deficit to the sand budget.

Net deposition and erosion zones along the Mississippi Sound barrier islands for the period 1917/20 to 2005/10 were isolated to define the regional sediment budget. This period encompasses a time of significant channel dredging activity at Horn Island Pass and Ship Island Pass. Furthermore, it includes some of the most devastating hurricanes to impact the northern Gulf of Mexico (e.g., 1916 hurricane, 1947 hurricane, Hurricane Camille, and Hurricane Katrina). Figure 9 illustrates the macro-scale sediment budget for the study area, which summarizes details from each of the five control areas along the coast for assessing net sediment flux

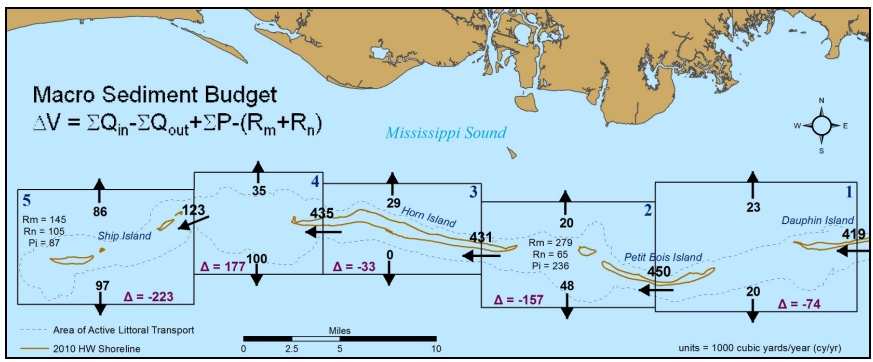

Fig. 9. Macro-scale sediment budget for the Mississippi Sound barrier island chain, 1917/20 to 2005/10. Arrows illustrate the direction of sediment movement and numbers reflect the magnitude of net sediment transport.

throughout the system. Black arrows signify the direction of net sand movement and numbers reflect the magnitude of sediment flux in thousands of cubic yards per year. Notation in Figure 9 shows an equation for balance of the sediment budget, in which Q_{in} and Q_{out} are sources and sinks entering and leaving each cell, respectively; P is the placement of sand within each cell; and R_m and R_n are the maintenance and new work dredging removed from the outer bar channels within each cell, respectively.

At western Dauphin Island, net sand transport into sediment budget Cell 1 is 419,000 cy/yr. This value was determined by updating the sediment budget of Byrnes et al. (2010) for Dauphin Island by including post-Katrina bathymetry data. Overall, the area encompassed by Cell 1 was a net source of sediment to downdrift beaches (450,000 cy/yr), the Gulf (20,000 cy/yr), and the Sound (23,000 cy/yr). West-directed sediment flux was by far the dominant direction of transport. In fact, spit growth along the western end of Dauphin Island and shoal accretion at Petit Bois Pass accounted for about 82% of the sediment flux from Dauphin Island. Approximately 54,000 cy/yr of sand from the Pass combined with erosion on the east end of Petit Bois Island to supply 450,000 cy/yr of sand to the west end of the island.

In Cell 2, sand flux to the western end of Petit Bois Island created an elongated sand spit that abutted the navigation channel at Horn Island Pass. Dredging records for the period 1918 and 2009 indicate that 279,000 cy/yr of littoral sand from the east was transported into and dredged from the channel. The remaining 171,000 cy/yr was transported into the Sound (10,000 cy/yr), offshore to the Gulf (16,000 cy/yr), and deposited along the spit and at entrance shoals east of the navigation channel (145,000 cy/yr). Although large quantities of littoral sand were deposited in and dredged from Horn Island Pass channel (Figure 9; R_m=279,000 cy/yr), most sand maintenance dredging was restored to the west lobe of the ebb shoal (P=236,000 cy/yr). As such, the flux of sand west to Cell 3 was reduced to about 431,000 cy/yr. Sediment losses to the Sound (20,000 cy/yr) and Gulf (48,000 cy/yr) were relatively small, but total sand placement seaward of the littoral zone as part of channel dredging (new work and maintenance) added to net sand export from this control area (ΔV=-157,000 cy/yr) and resulted in Cell 2 being a net sediment sink to longshore transport.

Erosion and accretion along the Gulf side of central Horn Island resulted in the addition of 33,000 cy/yr (ΔV) of sediment to the littoral transport system (Cell 3). However, it is estimated that erosion along the north side of the island provided about 29,000 cy/yr of sediment to Mississippi Sound, and no sand was transported seaward to the Gulf. Overall, Cell 3 is a source of sand for downdrift beaches and the entrance encompassing Dog Keys Pass and Little Dog Keys Pass (Cell 4).

Sand flux to Dog Keys Pass (Cell 4) was about 435,000 cy/yr, very consistent with transport magnitudes east of this area. Deposition along the western end of Horn Island and into Dog Keys Pass accounted for about 60% of the total sand flux into Dog Keys Pass. In 1917/18, Dog Island (also know as Isle of Caprice) was a low-relief sand island in the entrance between Dog Keys and Little Dog Keys Passes (see Figure 5) that remained subaerial until about 1932 (Rucker and Snowden 1988). Dog Keys and Little Dog Keys Passes create the largest entrance in the study area, and this dual inlet system is very active in terms of channel and shoal morphodynamics. Changes in flow dominance throughout the inlet have enhanced deposition on both ebb shoals, creating a net sediment sink for this area (ΔV=177,000 cy/yr in Cell 4). Furthermore, export of sand to the Sound (35,000 cy/yr) and the Gulf (100,000 cy/yr) have decreased the west-directed flux of sand into Cell 5.

As a result, the flux of sand to East Ship Island is about 25 to 30% of west-directed sand transport elsewhere in the system (123,000 cy/yr; Cell 5). The orientation of East Ship Island exposes low-lying sand beaches to direct attack by southeast waves. As such, a significant amount of sand eroded from Gulf-facing beaches along East Ship Island is transported to the back side of the island during overwash events. Rapid beach erosion has exposed old interior marsh and fine-grained backbarrier deposits that are estimated to contribute approximately 25% of eroded island sediment to offshore and Sound environments. Long-term erosion along East Ship Island mobilizes more than three times the amount of sand being transported to the island from Little Dog Keys Pass. The end result is chronic erosion along East Ship Island because the quantity of sediment eroded from the beach and nearshore in this area is substantially greater than the quantity entering Cell 5 from the east. Net erosion is the only possible result under these conditions.

Average annual maintenance dredging of Ship Island Pass navigation channel removed about 145,000 cy/yr, of which 87,000 cy/yr (60%) was placed back west of the navigation channel in the “littoral zone” placement area or around Fort Massachusetts, a historical fort on West Ship Island. However, analysis of bathymetric change between 1917/20 and 2005/10 (see Figure 8) illustrates that there are no transport pathways between the placement area west of the channel and Cat Island, as evidenced by no measureable changes to seafloor depths. As a result, we recommend backpassing dredged channel sand to fortify East Ship Island.

Conclusions

Long-term net transport of littoral sediment along the Mississippi Sound barrier islands is primarily unidirectional (east-to-west), with minor transport reversals at the eastern ends of islands where overall island orientation is modified by wave and

current processes to produce localized east-directed transport. Beach erosion along the east side of islands and sand spit deposition to the west resulted in an average sand flux of about 430,000 cy/yr east of East Ship Island. Littoral sand transport decreases rapidly on West Ship Island, where sand transport terminates at the navigation channel between West Ship and Cat Islands. Littoral transport along West Ship Island deposits approximately 145,000 cy/yr in Ship Island Pass channel, about half of maintenance dredging recorded for the Horn Island Pass channel.

Analysis of historical dredging records for the navigation channel at Horn Island Pass indicates that approximately 85% of maintenance sand removed from the channel was deposited within the littoral zone, which was available for transport downdrift to Horn Island. The remaining 15% may have been deposited outside the littoral zone, potentially resulting in a long-term sand deficit to downdrift littoral environments. However, shoreline and bathymetry changes west of Horn Island Pass indicate no measurable differences in change trends prior to and after major dredging activities.

One primary longshore deviation in the sediment budget for the Mississippi Sound barrier island system is the magnitude of deposition associated with Dog Keys Pass relative to other passes. Dog Keys Pass is the only sediment budget cell with a net surplus of sand (sediment sink; see Figure 9). It also is the widest pass in the system and has two active channels and ebb shoals. This combination of geomorphic characteristics results in a deficit of sand along East Ship Island. If beach and littoral zone restoration along East Ship Island is not implemented in the near future, the island may be expected to erode and become a subaqueous shoal, not unlike historical Dog Island/Isle of Caprice. Furthermore, the width of entrance between Horn Island and East Ship Island will increase, making sand bypassing to the remaining part of Ship Island even more difficult.

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